

# System Upgrade

## Realising the vision for UK education

Connect	Red
Share	Orange
Analyse	Yellow
Assess	Green
Apply	Teal
Personalise	Light Blue
Engage	Dark Blue
Streamline	Light Purple
Include	Dark Purple
Know	Light Green
Compute	Dark Green
Construct	Light Blue



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# Introduction: Technology Enhanced Learning Research Programme



**Richard Noss**

*Director*

The massive ambitions we share, as a nation, for education cannot be met without technology. Crucially, they cannot be met without technology designed to help people learn. For too long learning has been subsisting on the crumbs of technologies designed for other purposes. It is too important and too complex for that to continue.

The Technology Enhanced Learning research programme has spent more than four years developing systems and software that, for example, use artificial intelligence to teach teenagers algebra and help autistic children with their social skills. We have created virtual islands where young people acquire the confidence to tackle some of life's bigger challenges. We have exploited the potential of giant touch-screen tables to encourage young children to work together. We have taken sense-of-touch technology – the sort that makes that gaming controllers vibrate – and used it to train dentists cheaply and effectively.

The potential for learning is clear when we consider the technologies that are present in homes and in people's pockets. But there is little sign that this kind of technology is being adequately exploited for teaching and learning.

Of course some schools are pioneering the use of technology in learning. But too many are struggling with cumbersome networks and outdated computers and a fear of all that lurks on the internet. Meanwhile, their students are busy at home setting up servers to allow them to play online games, or making

videos to upload on YouTube, or socialising with their friends on Facebook. They and their parents may be perfecting their digital photos on their multi-touch tablet or doing the week's shopping online. Colleges and universities are making headway, but there is much more that can be done. And the possibilities for lifelong learning are endless, though yet to be thoroughly realised.

Driven by the desire to discover, create and communicate (and play and shop), people of all ages have developed impressive skills in order to pursue their own interests. Somehow, this has not yet transformed learning and teaching in the same way. Partly, this is due to a reluctance to change what counts as learning. All forms of professional life have been transformed by technology, but we are wary of making radical changes to what is taught and what is learned. Yet this is where change is most needed – to learn the new things that matter in the 21st century, and find new ways to teach and assess them.

There are signs of change: new technologies like tablet computers are helping to turn the tide as is the long-overdue recognition of the importance of teaching children something

about the art of programming. And of course almost everyone in the UK has a powerful computer in their pocket, even if they have to switch it off when they enter the school.

Education at all levels needs technology that is designed for learning and teaching, not the leftovers of systems designed for quite other purposes. Without it, our schools will languish, locked in an analogue mind-set while the rest of society goes digital. Our economy, our children – indeed all of us – will be the losers.

This report addresses 12 key themes, with recommendations that will be relevant to everyone involved in learning – including teachers, policymakers, lecturers and workplace trainers. Our ambition is to feed these into the debate, to provide focus and, where possible, evidence that can guide policy and practice. As such, our recommendations are not simply demands on government or a set of unrealistic calls on the public purse; they are an attempt to map out the territory of what we – academics, industry, policymakers and practitioners – should recognise as crucial for getting the best out of technology, and finding effective and productive ways to invest for the future.

### **The Technology Enhanced Learning (TEL) Research Programme is:**

- a £12m programme funded by the UK ESRC and EPSRC from 2007-2012
- designing and evaluating systems to advance our understanding of learning and teaching in a technological context
- supporting eight large interdisciplinary projects
- working to achieve impact for emerging research results and
- mapping progress on key themes

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# Mapping the territory: 12 key themes and recommendations

## 1. CONNECT

Technology-enhanced learning research is exploring how the worlds of informal and formal education can be connected. Organising access to school intranets, school-provided podcasts and social media at home is a start. But simply importing school into the home is not enough. Equally, allowing children to bring personal devices into the classroom can be seen as disruptive and dangerous. Yet evidence is emerging of the benefits of such devices when harnessed to target learning.

Technology-enhanced learning can reconceive the connections between formal and non-formal learning. Both worlds are transformed if young people are engaged in productive learning using personal technologies and networks within and outside the classroom.

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### RECOMMENDATION

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Exploit the power of personal devices to enhance learning.

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## 2. SHARE

Preparing our children for the future is hard when we don't have a clear idea of what the world will be like in 20 years' time. But one thing is certain. They'll need to be able to work together to solve problems. Teamwork is vital in the knowledge economy and there are new forms of collaboration that are not being exploited.

Technology can help, not just by encouraging people to work together, but by helping them profit from collaboration, to learn about things that would be difficult to learn alone. There are significant new gains that can be designed into technology-enhanced learning, preparing students for 21st century teamwork.

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### RECOMMENDATION

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Catch the wave of social networking to share ideas and learn together.

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## 3. ANALYSE

Technology can help us analyse and understand how people learn. As technology takes an increasingly central place in education, work, and in everyday life, it becomes vital to understand how people learn with it. We are fortunate that the same technologies that enhance learning also give us fresh insights into the nature of learning. This is because the devices that students use can also serve as microscopes revealing, in close-up, the details of their learning. So the technologies can help us make sense of the learning process. This is important if learning with digital devices is not to become just a speeded-up version of what we have done for decades. Making sense of how people learn can help teachers, lecturers and workplace trainers rethink how they teach.

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### RECOMMENDATION

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Use technology to understand better how we learn, and so help us learn better.

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## 4. ASSESS

Understanding how people learn with technology helps to solve a long-running problem: how to assess what really matters – the emergence of understanding – rather than what’s easy to assess – whether someone can follow the rules. For far too long we have all been like the drunk looking for his five-pound note under the lamp post – he knows that this is not where he dropped it, but there is no light to look anywhere else! Now, with the latest artificial intelligence techniques, it is becoming possible for new forms of assessment to assist teachers and students alike, to attribute meaning to what students do, and to help teachers optimise their strategies.

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### RECOMMENDATION

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Develop technologies to assess what matters, rather than what is easy to assess.

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## 5. APPLY

Everyone knows that it’s not always easy to apply the maths we learn in school to solve everyday problems. A substantial amount of time is spent in schools teaching people about ratios and percentages, but it doesn’t stop people getting into horrendous messes with their credit cards. A recent study showed that even people who spent all day looking at spreadsheets and talking to customers on the phone, had little idea how the numbers worked, or how to apply them to customers’ problems. And it’s not just an issue with maths. People can struggle to use any classroom learning in the outside world. Technology can help them make the learning they’ve acquired at school or college relevant to and useful in their work and leisure.

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### RECOMMENDATION

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Allow technology to help learners apply their education to the real world.

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## 6. PERSONALISE

Technology by itself doesn’t solve anything. The point is to design technology so that it addresses problems of learning and teaching. For example, we can design personalised technology which, courtesy of artificial intelligence, is sensitive to what learners know and how they work, and can adapt to optimise the feedback they receive. We are already used to computers that know our favourite websites, recommend what to listen to or read, and predict our text messages. This is just the tip of the iceberg: in the future, computers will know enough about us to offer a personalised learning, adapted to our strengths and styles. They can learn from us about how best to help us learn.

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### RECOMMENDATION

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Utilise artificial intelligence to personalise teaching and learning.

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## 7. ENGAGE

Technology is moving beyond keyboards and mice. Increasingly, IT systems are supporting interaction by touch or movement, for example Nintendo Wii.

We have known for decades that learning is embodied in movement. Young children often use gesture to express ideas before they use words, underlining the educational potential of these technologies. Learning can reside in the flick of a finger sending an object across a screen.

The recent advent of cheaper technologies for providing haptic (touch) feedback, mobile tablet computers, large interactive surfaces and low-cost movement detection systems, leaves us well-placed to deliver learning that is active and fun. And we can also gather data that helps us understand how embodiment really works.

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### RECOMMENDATION

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Go beyond the keyboard and mouse to learn through movement and gesture.

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## 8. STREAMLINE

Doctors, architects, musicians – all take for granted software that enhances their creativity and productivity. Teachers need tools like that too.

Thanks to technology-enhanced learning they can have them. We can design power tools for teachers to make learning more effective and their time more productive. We can help them share expertise, give them the opportunities to think more deeply about what they teach, how they teach it, and what their students are learning. And we can exploit AI techniques that ‘know’ what teachers want, tapping in to their needs and those of their communities to make the process of being an education professional more streamlined, more productive.

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### RECOMMENDATION

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Enhance teachers’ productivity with new tools for designing teaching and learning.

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## 9. INCLUDE

Many people are not able to take advantage of digital technologies, excluded from this major new medium for learning and for participating in the world. Nearly a fifth of the UK population makes little or no use of the internet. You know how it feels when you leave your phone at home? Technology can’t make up for inequalities based on race, or gender, or class, but without it, those gaps risk getting ever wider. With technology, the gaps can narrow. Technology-enhanced learning has the power to bring learning to anyone, anywhere, anytime. Enabling it to do so will help create a learning society for more people, and a more equal society for everyone.

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### RECOMMENDATION

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Empower the digitally and socially excluded to learn with technology.

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## 10. KNOW

Sometimes it feels as if we are struggling under an information avalanche. Yet the massive increase in the volume and diversity of information does not necessarily make us all more knowledgeable. Access to information by itself does not guarantee wisdom or insight – meaning must be added.

Where does meaning come from? Humans rely on context and culture to transform information into knowledge; computers can't do this – yet. Gradually though, as 'semantic web' tools come on stream, they are starting to gather meaning from the web, not just information. We need to learn how to use these powerful tools that link data and create new ways of looking at information – turning it into knowledge.

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### RECOMMENDATION

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Employ tools to help learners make sense of the information overload.

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## 11. COMPUTE

Computational thinking is a powerful and general way of exploring how systems and processes work, including societies, the spread of diseases, interacting technologies, and our own minds and bodies. As the world becomes more and more automated and digital, the language of computers needs to become the fluent second language of learners.

These kinds of new knowledge are the understandings required in the 21st century. We are living in a world of increasing interdependence and complexity. Science and maths underpin so much of everyday life yet too few people understand how they are done. Quite simply, this knowledge is currently owned by the 21st century digital priesthood – we have yet to democratise it. This knowledge is essential if we are to be productive and engaged citizens.

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### RECOMMENDATION

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Understand how computers think, to help learners shape the world around them.

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## 12. CONSTRUCT

Watching young children make sense of the world teaches us an important lesson: people learn best when they are making things, and sharing what they've made with each other. Reflecting on what you have constructed is a key part of learning. Until now, this lesson didn't easily translate into learning more generally – you couldn't make a model of the solar system, play around with the forces of gravity, or model the outbreak of the first world war. But now, with computers, literally anything is possible. Ideas that could only exist in the minds of people can now have a life on the screen. Not only does this bring them alive, it gives people the chance to construct their own mental representations alongside virtual ones.

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### RECOMMENDATION

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Unleash learners' creativity through building and tinkering.

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# 1 Connect

Exploit the power of personal devices to enhance learning.

Outside school, young people are enjoying and being empowered by personal technology. They can converse and be contacted anywhere, anytime. They can discover and share media and products. They can collaborate through social networks and multi-player games.

Contrary to the way these activities are often portrayed, research shows that they enable young people to develop powerful skills that employers want.

Inside school, the story is very different. Little has been done to link these digital activities with formal education. The status of schooling in society means that headteachers have to be cautious in adopting new curricula and teaching methods. This limits how they can engage students and connect with their out-of-school culture.

So what is the best way to connect the worlds of informal and formal learning? While young people can be given access to school intranets, podcasts and social media at home, doing so risks overloading their private lives with school. Conversely, allowing them to

bring their smartphones, netbooks and other personal devices into the classroom could be seen as difficult, disruptive, and – given the issues with internet access – potentially dangerous. Yet some researchers have shown that such connections can be beneficial when done in a well-considered manner.



## Learning technologies can reconnect the worlds of formal and informal learning.

These benefits include:

- helping children to learn in and out of school, through activities that start in the classroom and then continue in the home or outside, enhanced by technology that reinforces, extends and relates formal and non-formal learning;
- putting children in touch with the expertise and alternative perspectives of people other than their teachers, as well as increasing their awareness of places outside the classroom, strengthening the relevance of classroom learning;
- collecting data ‘in the wild’ to take back into the classroom, enabling authentic and original investigations that ground the development of abstract knowledge in observation and experimentation in the real world;
- unobtrusively capturing individual children’s interests and learning strategies;
- making use of communities and social interactions that happen outside the classroom.

Learning technologies can reconnect the worlds of formal and informal learning. Doing so successfully will see young people engaged in productive learning with personal technologies and networks within and outside the classroom.

# In action: Essa Academy

The Essa Academy<sup>1</sup> in Bolton has given young people the technology to transform learning – to make it, in their words, more ‘exciting, creative, inspiring and innovative’. As part of a drive to raise standards, it has provided each of its 900 pupils with an iPod Touch, which allows them to be in charge of their own learning inside and outside school.

Showk Badat, Essa’s principal, says this innovative use of technology is at the heart of the huge improvement in the academy’s results – up from 55 per cent to 99.5 per cent five A\*-C grade GCSES in two years. ‘The iPod Touch is a really motivational tool, empowering each child to explore his or her personal creativity and learning potential. It has done the most remarkable thing: removed the limits to learning.’

Communication between staff and pupils has improved with pupils happy to use the iPods to ask for help or advice. Teachers can also use them to monitor all their pupils’ progress in a lesson. Meeting one of their biggest challenges is made easy by being able to monitor responses to questions sent to everyone simultaneously. Other uses include doing

online research; accessing dictionary and thesaurus tools; accessing other useful apps.

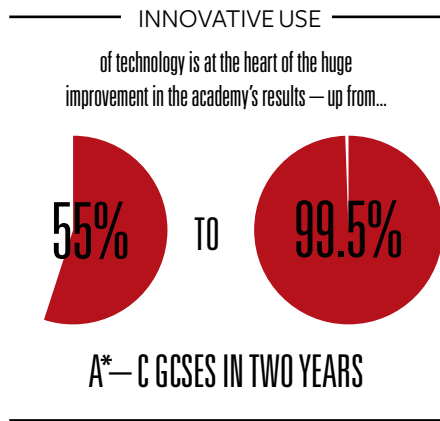
The Essa initiative is also bringing parents into school and involving them in their children’s education, something that has proved difficult in the past.

Pupils are using technology to communicate with the wider world. They produced a documentary of the academy’s innovations, including interviews with teachers and pupils, for the BBC News ‘School Report’ initiative.<sup>2</sup> And they made a YouTube video<sup>3</sup> on how technologies such as laptops and handheld devices are transforming their learning.

<sup>1</sup> [www.essaacademy.org/](http://www.essaacademy.org/)

<sup>2</sup> [www.youtube.com/watch?v=10CfQ5joBHU](http://www.youtube.com/watch?v=10CfQ5joBHU)

<sup>3</sup> [www.youtube.com/watch?v=ScNZM8rU4rc](http://www.youtube.com/watch?v=ScNZM8rU4rc)





## 2 Share

Catch the wave of social networking  
to share ideas and learn together.

When computers first appeared in classrooms the fear was that they would isolate students from each other and, perhaps, from their teachers. Here, surely, was a dangerously absorbing technology with the power to encase users in a bubble of private concentration. In fact, the opposite has turned out to be the case: Technology has cultivated a form of learning that is more social in quality than its predecessors.

In the early days of computing there were too few computers and too many students wanting to use them. Students had to work together at these machines and – perhaps to their surprise – teachers found that these collaborations could be lively and constructive.

Since then, working together around and through computers has continued to evolve. But technology could do even more to support this social learning. And it should do so because such learning has become increasingly valuable.

According to educational psychologists, joint problem solving and inquiry encourages social and intellectual development. It puts students under pressure to articulate their views and, in particular, to reconcile them

with the views of others. This collaboration is a potent preparation for the demands of team and group activity in working life. Both individuals and organisations often make progress through coordinated forms of social thinking such as ‘brainstorming’. If we wish to encourage students into ways of thinking that make the most of collaboration then we should recognise how technology can help.



### Technology has cultivated a form of learning that is more social in quality than its predecessors.

Perhaps the image most readily conjured up by the notion of collaborative learning is a pair of students working together, heads down, in a classroom. Yet, thanks to networked technology such collaborations need not be constrained by classroom walls or school timetables.

Networked technology can create a kind of ‘distributed thinking’, as students work together

across time and space. One example of this is found in the potential of mobile technologies to support distributed fieldwork explorations. Another example is in higher education where distance learners work in groups, but at their own speed on university courses.

Technology can extend the traditional model of a collaboration from a short, intimate, private episode of problem solving to one that is distributed across time, space and participant structure. Technology can also extend collaborations to involve experts – making possible their short-term engagement with a problem.

Collaborative learning is increasingly important for students and technology offers powerful support for such experiences. Technology can help team members communicate their understanding of problems and make the components of those problems easier to grasp. Technology can free collaborations of the restrictions of time and location. Finally, it can enable collaboration to become a more loosely coupled affair: drawing in new sources of expertise that continue to be ‘social’ in nature.

# In action: Personal Inquiry Project



Technology can extend the traditional model of a collaboration from a short, intimate, private episode of problem solving to one that is distributed across time, space and participant structure.

The Personal Inquiry project<sup>4</sup> was set up to help young people develop the investigative skills needed in modern science. Using a tailor-made computer toolkit called nQuire2, pupils work together to research issues that affect their lives – whether they are at school or at home, in a town centre or a nature reserve.

The nQuire2<sup>5</sup> software runs on both mobile and desktop computers. It guides and supports young people through their investigation by giving them structured activities, data probes, visualisations of data, and a fluid means of communication.

nQuire2 was tested out by more than 150 secondary students researching urban heat islands in Northampton and Milton Keynes. This study of the phenomenon of towns being warmer than surrounding rural areas was a major component of their GCSE geography work for several months. They used sensors to collect environmental data in the field as well as to support analysis and presentation back in the classroom.

During a fieldtrip, the students used Sciencscope data loggers and sensors

to monitor wind speed, temperature, infra-red irradiance and carbon monoxide data, and took GPS readings of the data collection locations. Working in groups of four, they entered the information into the nQuire toolkit running on PC netbooks. They were encouraged to add text comments for each location and to take photos. Their teachers then integrated the results of their investigations back into their lessons.

The nQuire2 toolkit also enabled pupils to access expert help. For example, 14-year-olds gained input from a nutrition expert in their project on healthy eating. Similarly, in an investigation into the effect of noise pollution on bird feeding, pupils were able to work with two university experts in animal behaviour, so expert knowledge became part of the collaborative problem solving.

<sup>4</sup> [www.pi-project.ac.uk](http://www.pi-project.ac.uk)

<sup>5</sup> <http://www.nquire.org.uk/>





Students working together on the 'urban heat islands' fieldtrip.

# 3 Analyse

Use technology to understand better how we learn, and so help us learn better.

Education is far less tied to traditional classrooms and now happens at home, with friends and online. With technology playing an increasingly key role in its liberation, it becomes important to understand how people learn with it.

Without that understanding, the evidence-informed design of technology-enhanced learning systems is hampered, limiting our ability to provide rich and effective educational experiences. Luckily, the same technologies that enhance learning also enable us to gain insights into the nature of learning. This is because the devices that students use can also serve as microscopes, revealing in close-up the details of their learning.

Researchers in education now ‘data mine’ the records of thousands of students’ interactions with technology-enhanced learning systems. Data-mining is revealing which curriculum components pull their weight in terms of learning outcomes, very difficult information to collect in traditional ways. It can also be used to study how students use online social networks, experiment with new forms of

information presentation and feedback, discover the extent to which students differ, and encourage collaborative learning. And it means that learning technology systems can be continually improved on the basis of real-world evidence.

Such evidence has told us in the past that learning can benefit from a cyclical approach and from a social one. A learning cycle might consist of traditional teaching followed by a phase in which students explore material on their own or in small groups. By observing others, they learn what works and what not to bother trying themselves. Importantly for their academic self-esteem, they also come to understand that they are not unique in their misconceptions and misunderstandings.

Technology-enhanced systems enable new and large-scale forms of social learning that provide powerful experiences for students and masses of data for researchers. A good example is social network behaviour, understanding how networks of people come together and move apart, how they access and create information, and how they construct individual and group knowledge.

Such social learning underlines the complementary relationship between technology and education – what technology discovers about learning being used to shape how technology promotes learning and vice versa.

Take the example of gaming. Educational games are increasingly seen as a compelling way of engaging students. Difficult concepts can be accessed in ways that are interactive and concrete, and players motivated to explore them because the games are fun. But the key challenge for designers is ensuring that educational games have a positive influence on learning rather than one that is negative or distracting. One answer is to log students’ interactions with games and use the data to determine how well they are learning, whether their performance is influenced by issues such as gender and how the game itself can be improved.

# In action: Zombie Division



Divide and rule... Matrices meets some warrior skeletons.

Zombie Division<sup>6</sup> is a 3D adventure game which helps eight to 11-year-olds with maths. Matrices, the hero, explores a labyrinth populated by skeletons of warriors with numbers on their chests. To complete the maze, Matrices must engage some of these warriors in combat and defeat them; others he must avoid as he cannot overcome them. The key characteristic of the design is that the mathematical ideas – identifying number patterns, multiples, primes, factors and squares – are embedded in the game, not just added ‘chocolate-covered broccoli’.

This embedding is achieved by providing Matrices with three weapons to divide opponents. If he chooses appropriately, he defeats the warrior skeleton, but if he makes a mistake the skeleton will attack him instead.

Zombie Division doesn't just help children improve their maths skills. It also logs their performance in order to provide teachers with valuable information. They can see what division problems a particular child finds difficult or easy. They can discover if factors such as gender, amount of game experience or mathematical knowledge influence their ability to play and learn.

Data can also be scrutinised to see if children can apply what they've learnt in the game to other contexts. For example, their performance when dividing a number on a skeleton can be compared to how they get on doing the same calculation in a typical maths lesson.

In trials children performed better on the ‘skeletons’ than they did on the numbers; but still did better on the numbers if they had first practised on the skeletons. Such data can be used by parents and teachers to ensure children practise appropriate tasks, help designers find features that make games effective and help researchers understand why we learn more when having fun.

<sup>6</sup> <http://zombiedivision.co.uk/>



**Data-mining is revealing which curriculum components pull their weight in terms of learning outcomes, very difficult information to collect in traditional ways.**



# 4 Assess

Develop technologies to assess what matters,  
rather than what is easy to assess.

'If you mention computers and testing in the same sentence, the first things most people think of are long sequences of multiple-choice questions, and specially designed answer cards filled in with No. 2 pencils.' So observed David Michael and Sande Chen<sup>7</sup> in their 2005 report on the potential of 'serious' video games both to promote and assess learning.

To some extent this is still true. Assessment methods need to be better aligned with our current understanding of how people learn. Too many high-stakes tests are administered to individual students in examination rooms, contexts far removed from those in which learning originally took place.

Improving assessment is important for reasons of equity, validity, and compliance with government policies on, for example, e-portfolios and inclusion. But reforming assessment is difficult because it requires change at all levels of an educational system – from classroom to government.

For the first time, we can assess what really matters, rather than simply what is easy to assess. We need to move beyond 'snapshots'

of students' performance towards assessments that track how their learning is developing over time. Assessment that is rooted in ranking students and schools needs to give way to a more enlightened approach that works 'harder' to provide:



### Assessment rooted in ranking students and schools needs to give way to more enlightened approach.

- useful diagnostic feedback to students about their learning;
- useful information to teachers;
- a solid basis for evidence-based decision making for policymakers.

This means assessing the process as well as the product of learning – the 'how' as well as the 'what'. Currently, assessment may inhibit creativity and turn enthusiastic, inquisitive students into results-driven people desperate

to avoid making mistakes. As anyone who has suffered exam nerves knows, traditional modes of assessment are too sensitive to stress, illness and emotional upsets.

Assessment also needs to be rethought because it is increasingly out of kilter with contemporary teaching and learning. Compared to days gone by, students now work much more collaboratively and cooperatively on group projects at school and university. Inquiry learning is common, with learners encouraged to ask questions about the world, to collect data to answer their questions, and to make and test their discoveries. Technology allows for the sophisticated assessment of students' inquiries and the results of those inquiries, be they in the form of hypotheses or models.

<sup>7</sup> Michael, M. & Chen, S. (2005) Proof of Learning: Assessment in Serious Games. Gamasutra website: [http://www.gamasutra.com/view/feature/2433/proof\\_of\\_learning\\_assessment\\_in\\_.php](http://www.gamasutra.com/view/feature/2433/proof_of_learning_assessment_in_.php) (accessed Jan 5th 2012)

Another source of misalignment concerns multimedia. Students now learn, communicate and socialise via e-books, websites, social network websites, simulations and a plethora of other multimedia. They routinely communicate their learning via written and spoken English, mathematical and logical notations as well as diagrams, digital photographs, videos, charts and graphs. Assessment needs updating so that students can demonstrate their learning in the same wide range of forms that they encountered during its acquisition.

Finally, assessment needs to reflect a wide variety of teaching and learning practices such as project-, inquiry- and problem-based learning, in other words learner-centred as well as teacher-centred practices. Such methods can engross students in their work, but their engagement – and their performance – often plummets during formal assessment.

By contrast, e-assessments have the potential to engage students in immersive, meaningful and challenging activities which provide them and their teachers with rich insights into their reasoning and knowledge. For example, using



data-mining techniques, researchers analysed the help-seeking behaviour of 1,400 students who used an intelligent tutoring system for high-school geometry. They reported that not only could they better assess students while teaching them, but also that the assessment could be done more efficiently. These results suggest that there may be no need to differentiate between ‘teaching’ and ‘testing’ – over time, learning is reliably indicated by how a student responds to teaching. Tracking how much help a student needs with a task will result in as valid an assessment as a traditional test taken after teaching has ended.

JISC<sup>8</sup>, which champions the use of digital technology in education, advocates technology-based portfolios known as e-portfolios. It says they encourage ‘profound forms of learning’, as well having a role in professional development and accreditation, and the potential to support students moving between institutions and stages of education.

<sup>8</sup> <http://www.jisc.ac.uk/>



# In action: PATSy



PATSy allows medical students to repeatedly practise their skills on more than 60 virtual ‘patients’.

Dr Helen Kelly always keeps a special patient up her sleeve for when she has to assess her speech and language therapy students at University College Cork. As the dreaded day looms, she can determine the complexity of the case by altering the number of clinical evaluations available to her students. The range should be ‘enough for them to make a differential diagnosis, but not too many so as to overwhelm them’.

Dr Kelly’s obliging patient comes courtesy of PATSy<sup>9</sup>, an established online case-based resource. PATSy allows medical students to repeatedly practise their skills on more than 60 virtual ‘patients’. Used in medicine, health science and clinical psychology, the system provides students with interactive virtual patients as well as real data in the form of videos, assessments, and anonymised medical histories.

PATSy, recently used as the core platform in a large research project<sup>10</sup>, allows students to sharpen up their clinical skills as often as they like – even on the same patient. It is real learning by doing.



Unlike a real patient PATSy is available any time, any place. A case of assessment successfully contributing to students’ learning as well as evaluating it.

Dr Kelly says that PATSy ‘gives students real-life data to practise their clinical skills in assessment, differential diagnosis and linking theory to clinical work. It allows measurement of their clinical decision-making skills as well as their theoretical knowledge’.

<sup>9</sup> [www.patsy.ac.uk](http://www.patsy.ac.uk)

<sup>10</sup> [www.tlrp.org/proj/phase111/cox.htm](http://www.tlrp.org/proj/phase111/cox.htm)

# 5 Apply

Allow technology to help learners apply their education to the real world.

A good way to learn about a volcano is to visit one. Similarly, driving a racing car makes it easier to understand the physical forces involved. However, such lessons are difficult to organise and some – such as observing the effects of changing gravity to understand better how it works – may simply be impossible. Here's where technology can help.

People need to be able to use what they have learned at school to solve problems in everyday life. But they find this difficult. Their struggles to apply or 'transfer' their learning have vexed psychologists and educators for decades and represent an important issue for society. We need citizens who can use their education to help themselves, their colleagues and society to prosper. They need to be able to come up with answers using the general principles they have been taught. And they also need to be able to do the opposite – to extract general principles from the experience of solving everyday problems.

At the start of the 20th century, the American psychologist Edward Thorndike showed that just because someone had the knowledge or skill

to pass a test did not mean that they could take advantage of that knowledge or skill in a different situation. Much has been discovered since then about how to help people apply their learning.



### 'Augmented reality' — where the real world is overlaid with information from the digital world — hugely expands the variety of problems students can study.

We now know that it helps if people are able to tackle a problem 'for real', if they can vary the situations in which the problem occurs, and if they can see it from a variety of perspectives. It also makes a difference if they can join in activities that are 'multi-representational' – allowing them to see and manipulate representations of the same thing in different ways, exploiting the potential of dynamic images, colour, sound and so on.

Computer-based simulations, games and 'augmented reality' – where the real world

is overlaid with information from the digital world – hugely expand the variety of problems students can study, and their ability to use this new knowledge. Simulation authoring tools such as SimQuest<sup>11</sup>, enable them to explore, for example, the physics of motion with skaters on ice, trains on railways and lorries on roads.

Some people excel at judging the extent of their understanding and the standards of their work. This self-knowledge or metacognition influences their ability to apply their learning. Ideally, everyone needs to be able to evaluate the extent to which they have reached a solution and to assess their own learning needs. Technology can help people develop their metacognitive skills, through, for example, enabling them to see and interact with a description of their performance on a task<sup>12</sup>. Software also exists that can build a model of a learner's developing metacognitive skill and offer *personalised* feedback to hone these skills.

<sup>11</sup> <http://www.simquest.nl/learn.htm>

<sup>12</sup> <http://www.eee.bham.ac.uk/bull/lemore/examples.html>

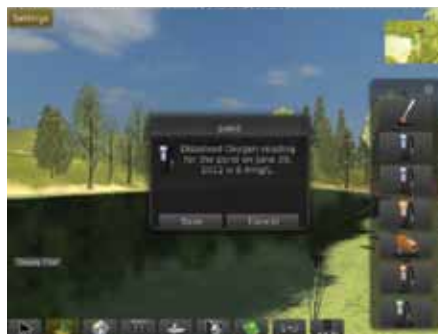
# In action: EcoMUVE

Ecosystems are complicated, requiring students to be able to reason about complex causal patterns. As these patterns often clash with students' preconceptions, they can struggle to acquire and apply their knowledge. To help them, Professor Chris Dede and colleagues at the Harvard Graduate School of Education developed the EcoMUVE<sup>13</sup> curriculum. This multi-user virtual environment offers students two immersive, simulated ecosystems in which to conduct scientific investigations.

One of these virtual worlds is a pond in which fish have been mysteriously dying. Students can explore the pond, including under the water. They can investigate the surrounding area, observing the plants and animals in their natural habitats. Their task is to work together, collecting and analysing data, in order to solve the puzzle of why so many fish have died.

The system helps students gain deeper understanding of difficult concepts, which helps them apply their learning in different situations.

EcoMUVE is now complemented by the EcoMOBILE system<sup>14</sup>. This combines



Taking water quality measurements at the EcoMUVE pond.

'augmented reality' technology and environmental probes so that students can visit a real ecosystem, such as a pond, and use their mobile devices to collect data.

Students walk to a 'hotspot' identified by the mobile device. It prompts them to investigate the organisms they find, asking questions about their observations, and giving constructive feedback based on their answers. They can also watch a video simulation of an atom involved in a process such as photosynthesis to help them



A green marker shows direction and distance to the next hotspot.

understand the flow of matter. And they can accept some information and guidance from a virtual adviser.

Overlaying this virtual data, information, simulations and visualisations on to experiences in the real world helps students apply formal science concepts to the solution of practical problems.

<sup>13</sup> <http://ecomuve.gse.harvard.edu>

<sup>14</sup> <http://ecomobile.gse.harvard.edu>

The virtual person offers information and guidance to support specified activities in a particular place.



# 6 Personalise

Utilise artificial intelligence to personalise teaching and learning.

From HAL in *Space Odyssey*, through C-3PO and R2-D2 in *Star Wars*, to Sonny in *I Robot*, Hollywood has been good at making money out of our fascination with machines that think and behave intelligently. And it's no longer science fantasy.

We have computers that can fly planes, model countries' economies, search the internet and predict what we want to type into a text message. We're also developing computers with human qualities such as the ability to understand language and recognise visual images.

Education can take advantage of all this progress. Tailor-made learning is within our grasp as artificial intelligence (AI) empowers computers to deal with the fact that everyone is different. We differ physically, emotionally and cognitively – and in our ability to understand how we learn and when we need help.

An education that recognises these differences can help everyone achieve their potential. Such personalised learning requires teachers, tutors, parents and mentors to ensure that every student works on problems

that are appropriate for them, problems that stretch them and help them progress.

Software that uses AI can help ensure that learners receive relevant feedback, whether working individually or as part of a team. It can give them valuable information about their performance, enabling them to manage their own learning and emotions.



**Tailor-made learning is within our grasp as artificial intelligence (AI) empowers computers to deal with the fact that everyone is different.**

Education systems with AI are very adaptable. They can respond quickly and appropriately to information about what the aim of a lesson is, who the students are, who is working with whom and where it is all happening. And they can do this even if the information changes or is incomplete. The capacity to adapt to students' abilities, needs, circumstances –

even their moods – is underpinned by sophisticated AI techniques.

There are three main ways in which AI techniques are used to develop 'adaptive software' systems:

### **Building computer models that can act as scientific tools**

ThinkerTools<sup>15</sup> is a microworld that allows 10 to 14-year-olds to test their ideas and understanding of forces and motion. Students can run simulations of objects moving and observe how various forces such as impulses, gravity, and friction impact on these objects. The software can be set up to run according to Newtonian laws, and also according to other laws of physics. Students can run existing simulations or create entirely new microworlds, including game-like simulations with targets, and timers.

<sup>15</sup> <http://thinkertools.org/Pages/force.html>

### Enabling a learning environment to adapt to input from learners, teachers or others

Andes Physics Tutor<sup>16</sup> is an intelligent homework helper, popular in the United States. Students are presented with a physics challenge, requiring them to, for example, draw vectors or coordinate systems, define variables or write equations. Andes provides them with feedback every step of the way and encourages them to use helpful problem-solving strategies. It also changes its advice in response to the kind of error the student makes.

### Designing computer models based upon a particular theory of learning

The Ecolab<sup>17</sup> software simulation environment is intended to help eight to 10-year-olds explore food chains and webs. It is based on our understanding, courtesy of Russian psychologist Lev Vygotsky, that children make good progress when their learning is 'scaffolded' or supported by a skilled adult.

<sup>16</sup> <http://www.andestutor.org/>

<sup>17</sup> <https://sites.google.com/a/kl.ac.uk/ecolab/>



AI techniques create convincing social simulations that can process students' speech and behaviour, engage in dialogue and non-verbal interaction.

## In action: Alelo

Imagine learning how to argue about the standard of your accommodation in France by standing in a hotel lobby having a heated conversation with the manager. Not only would you acquire the words, but you would also assimilate the body language and pick up tips on how to behave in such a situation. That, in essence, is the kind of lesson offered by Alelo's 'virtual-world simulations of real-life social communication'.

Alelo's Operational Language and Culture Training System<sup>19</sup> uses a virtual game-based environment and interactive lessons to provide foreign language and culture training. AI techniques create convincing social simulations that can process students' speech and behaviour, engage in dialogue and non-verbal interaction, and evaluate their performance. Independent evaluations have shown significant gains in students' knowledge of language and culture and greater self-confidence in their ability to communicate.

<sup>19</sup> [www.tacticallanguage.com/](http://www.tacticallanguage.com/)



# In action: Echoes

Andy is adept at using his intelligence to improve the social skills of young children, particularly those on the autistic spectrum. Through interacting with this virtual boy who inhabits a touch-screen magical garden, five to seven-year-olds are encouraged to practise skills related to 'joint attention'. This crucial skill, by which one person makes another aware of an object or event by pointing or looking at it, is often missing in children with autism.

Andy plays with the children, coaxing them to, for example, pick flowers or stack pots. Thanks to AI modelling, he can 'see' his young users, reason about their actions and, crucially, tailor his responses to them in the light of his observations and inferences.

Andy is the invention of Echoes, one of the Technology Enhanced Learning research programme's projects<sup>18</sup>. Echoes researchers have equipped him with an underlying personality that influences his actions – much like a human, albeit in a simplified way. This means he can emulate, using AI techniques such as planning, at least some human behaviours such as having goals and acting on those goals based on his understanding of the current state of the world.



A child enjoys a game in the magic garden with Andy, the artificially intelligent Echoes agent.

Andy's built-in AI allows him to have credible interactions with children – and they generally enjoy the opportunities he gives them for exploration and experimentation. They also enjoy having a go at the challenges he sets, particularly the immediate feedback minus any real-world consequences. The fact that the scenarios can be repeated endlessly gives them both pleasure and a sense of control over the Echoes environment.

<sup>18</sup> <http://echoes2.org/>



Andy's built-in AI allows him to have credible interactions with children – and they generally enjoy the opportunities he gives them.



# 7 Engage

Go beyond the keyboard and mouse to learn through movement and gesture.

Young children can struggle to master a mouse or a keyboard, yet it is through these devices that most are introduced to the world of digital technology. Fortunately this is changing. Engagement with technology is becoming easier through touchscreen devices such as the iPad and game consoles such as the Nintendo Wii or Microsoft Kinect that respond to children's gestures and body movements.

The popularity of such devices with children has, unsurprisingly, generated excitement in their educational potential. Our challenge is to better understand how these new ways of directly engaging with technology can enhance learning. This will not only help us decide which devices to use and how, but also inform the design of new, more effective technologies.

Children find new technologies exciting, and they can make learning more active and fun. However, there is always a risk of the novelty wearing off and what may be more significant is that new devices make interaction with technology easier. Indeed, devices such as the iPad offer exciting digital interaction even to infants.

Making it easier to manipulate technology doesn't only benefit young learners. Digital materials can represent different ideas, and new forms of interaction can facilitate, and extend, the way these ideas can be manipulated and explored. For example, number blocks can be slid around a touch screen using fingers on both hands, or images can be enlarged or reduced with a 'pinching' gesture. As technologies become more adept at recognising specific gestures, learners will be able to manipulate and investigate digital information more and more seamlessly.

There is increasing support for the idea that the way we think may be 'embodied', or inseparably linked to our physical experiences. Evidence has largely come from the way that we use gestures when explaining ideas, for example, moving our hands up and down to explain the notion of balance. These gestures do not just help listeners' comprehension; they help the speaker's own thinking.

Significantly, children are often able to express ideas through gesture before they can do so verbally. This has important implications for new forms of technology because devices can

capture and respond to particular actions that relate to concepts being learnt. For example, by linking the acceleration of a handheld device to an on-screen representation, children can explore how their physical movements link to concepts of motion.

To understand how new technologies can enhance embodied learning, we need to identify the relationship between thoughts and actions. In this regard, concepts that were once considered rather 'abstract', such as many mathematical ideas, are now being examined in terms of embodiment, raising the possibility of using new technologies to enhance learning in these areas. The Embodied Design Lab<sup>20</sup> in California, for example, is looking at developing children's understanding of proportion. Building on the fact that children's understanding is often first expressed through gesture, they are investigating how a gesture recognition device (the Wii in this case) can help them explore and reflect upon the physical components of their understanding.

<sup>20</sup> <http://edrl.berkeley.edu/>

# In action: SynergyNet



Children are often able to express ideas through gesture before they can do so verbally. This has important implications for new forms of technology.

New technologies make it easier for several people to interact with digital information at the same time. Multiplayer games on the Wii and multi-touch devices, for example, offer exciting new ways for children to play and learn together.

The potential of multi-touch devices is currently being explored by SynergyNet<sup>21</sup>. In this Technology Enhanced Learning programme research project, children work at one of four large multi-touch tables, a little like giant iPads. The tables allow them to work on their own or with others; manipulate different forms of information such as text and diagrams; and communicate with other groups by ‘sliding’ an item off their table towards another table. Initial findings indicate that using the tables encourages the children to have more task-focused conversations and increases their joint attention.

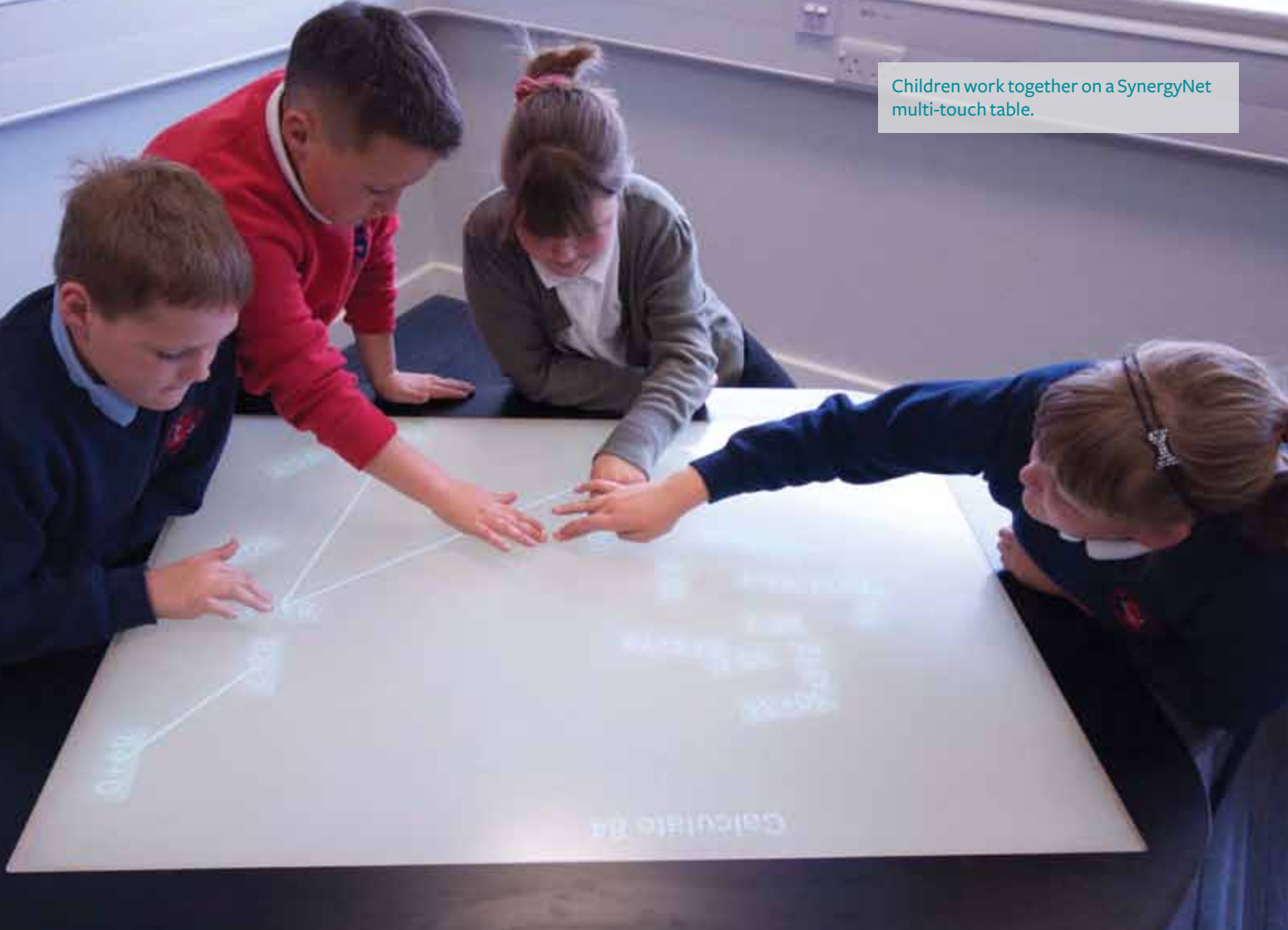
As well as observing how new devices influence children’s learning, the SynergyNet researchers can also use the tables to record children’s interactions, including gesture, providing rich data on the relationship between their actions and their thinking.

Such information is particularly important given the increasing evidence that the ideas that children develop are strongly related to particular physical actions.

Whilst considering the benefits of new forms of interaction, we need to recognise the fundamental role played by educators in mediating learning with these tools. Indeed, a significant aspect of the SynergyNet project has been to identify ways to support the teacher in orchestrating learning with new forms of digital interaction.

<sup>21</sup> <http://tel.dur.ac.uk/synergynet/>

Children work together on a SynergyNet multi-touch table.



# 8 Streamline

Enhance teachers' productivity with new tools for designing teaching and learning.

If technology-enhanced learning's capabilities are carefully designed, it can help teachers foster active independent learning in several ways:

**Active learning:** multimodal technologies (pictures, videos, sounds, animations, text) help teachers explain concepts and rehearse skills in engaging ways. They can also set inquiry learning activities that students work through at their own pace as, for example, in Stanford University's Star Legacy<sup>22</sup>.

**Independent social learning:** online technologies allow students to support each other in teacher-structured discussions as, for example, in the Interloc<sup>23</sup> games that promote dialogue and debate.

**Adaptive, personalised learning:** simulation and modelling environments mean teachers can give students intensive practice on intellectual or skill-oriented challenges. Feedback is meaningful, changing in response to how well – or not – the student is progressing. Such personalised feedback encourages them to spend more of their own time practising – making the exercise even more worthwhile.



In the hapTEL project, comparison with control groups showed that the simulation group learned at least as well, but more efficiently and cost effectively.

The value of this approach has been shown by hapTEL<sup>24</sup>, one of the eight Technology Enhanced Learning research programme projects. Dental students are trained on virtual jaws equipped with haptic or sense-of-touch technology. They can feel exactly what it is like to drill in to a tooth and the system gives them instant feedback on how much decay they have removed. With an inexhaustible supply of virtual teeth, they have endless opportunities to practise.

**Collaborative learning:** user-generated content tools (digital documents, virtual 3D environments, videos, spreadsheets) and online discussion forums allow teachers to devise activities in which students can work and learn together. Students submit the final product, whether it is a shared understanding or a polished skill, to their peers for constructive comment and then on to their teacher for formative feedback.

Technology-enhanced learning makes it possible for teachers to promote learning without being physically or even virtually present. Instead of teaching through lectures, class presentations and tutorials, teachers can use multimodal web resources, simulations and online peer support. This maintains, or even improves the quality of learning experience. It can also make teachers more productive as some variable-cost activities (linked to student numbers) switch to fixed-cost (technology-enhanced learning) activities. With fewer variable-cost activities student numbers can

<sup>22</sup> [http://aaalab.stanford.edu/complex\\_learning/cl\\_star.html](http://aaalab.stanford.edu/complex_learning/cl_star.html)

<sup>23</sup> <http://www.interloc.org.uk/>

<sup>24</sup> <http://www.haptel.kcl.ac.uk/>

increase without a corresponding increase in teacher time.

It's expensive to develop technology-enhanced learning resources and activities, so for low student numbers the per-student cost is high. As numbers increase technology-enhanced learning becomes much more cost efficient.

For example, a teacher might currently spend three hours preparing materials for six two-hour tutorials during which she will teach a total of 24 students. By contrast, the same teacher could spend eight hours preparing web resources for 48 students to work online in independent groups, and then 15 minutes with each group helping them sum up what they have learnt. The conventional approach has taken 15 hours of her time for 24 students. The technology-enhanced learning approach has taken 11 hours and helped 48 students.

Peer support is crucial here, and the key to success is the *online activity*. If it is well designed, it can promote active, as well as independent and collaborative, learning while preserving the all-important teacher feedback.

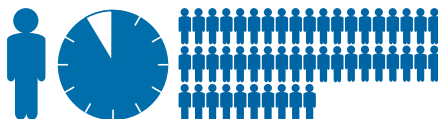
#### — ONE TEACHER COULD SPEND... —

##### CONVENTIONAL APPROACH



3 hours prep + 6x2 hour tutorials = 15 hours to teach 24 students

##### TECHNOLOGY ENHANCED LEARNING APPROACH



8 hours prep + 12x15 min tutorials = 11 hours to teach 48 students

We know that 'collaborative learning' activities are hard to get right, and teachers need help designing them. Perhaps technology-enhanced learning has a role here too?

Teachers already help each other by sharing resources and lesson plans, or learning designs – distillations of the best of teaching practice. Technology-enhanced learning can make

sharing more efficient. At university level, the Open Educational Resources (OER) movement has already funded collections of online learning resources, such as MERLOT<sup>25</sup>, Jorum<sup>26</sup> OpenLearn<sup>27</sup> and the MIT open courseware initiative<sup>28</sup>.

Teachers could draw on existing learning technology resources to save substantial amounts of time, but we need to understand the different metrics of teacher time: it may take 100 hours (for a teacher and technical assistant) to create a good animation resource; how many hours does it take another teacher to find it, evaluate its relevance, and weave it into their teaching approach? Five? Ten? It will vary, of course. And what is the best way of weaving the animation into their teaching? Tried and tested exemplars would help.

This is why teachers need to share the learning designs they have found to work, for example, to help students collaborate on a summary of what they have learned from the animation resource identified by their teacher.

<sup>25</sup> [www.merlot.org](http://www.merlot.org)

<sup>27</sup> [www.openlearn.open.ac.uk](http://www.openlearn.open.ac.uk)

<sup>26</sup> [www.jorum.ac.uk](http://www.jorum.ac.uk)

<sup>28</sup> [www.ocw.mit.edu](http://www.ocw.mit.edu)



# In action: Learning Designer

Teachers, like all professionals, need technology to help them become more productive. They are design professionals, working out every day how best to help their learners achieve their aims, and revising their methods on the basis of what happens in practice. They need design tools to capture their pedagogic ideas, test them out, and rework them, building on



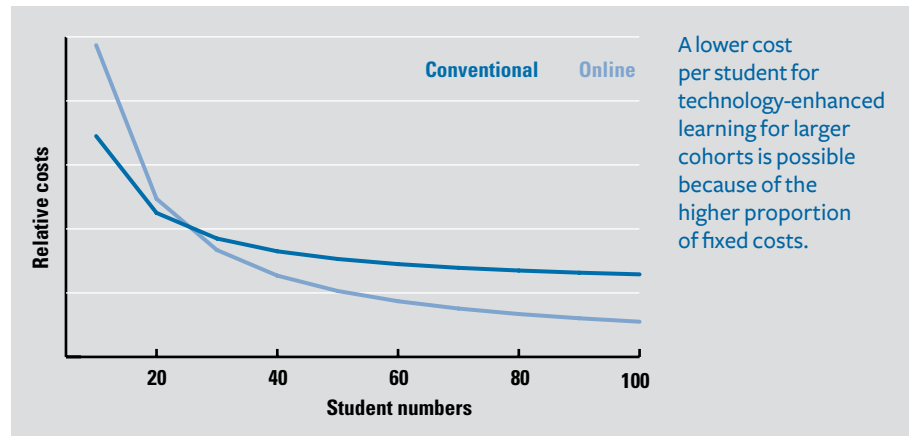
The Learning Designer analysis screen shows the implications of the design for the overall learning experience (pie-chart) and for teacher workload, depending on whether they reuse an existing resource, or develop it from scratch.

what others have done before and sharing their results with their community.

The Learning Designer<sup>29</sup> is a tool to help teachers with the difficult task of working together to improve learning. A TEL programme research project, it gives them a way of expressing their best ideas, using formal categories, such as learning outcome, teaching-learning activity, learning experience, duration, group size, and so on.

The design tool can ‘understand’ and analyse teachers’ ideas, and provide feedback on their implications for students. By collecting learning designs, it can also make it easy for teachers to find similar designs, adopt and adapt each others’ ideas, and so build a growing repository of good ways of teaching and using technology.

<sup>29</sup> <https://sites.google.com/a/lkl.ac.uk/ldse/>



# 9 Include

Empower the digitally and socially excluded to learn with technology.

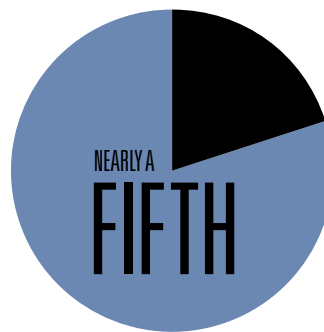
In this wealthy, technology-rich country, nearly a fifth of people rarely, if ever, venture online. Millions are excluded from the digital revolution, unable to access or make good use of the devices the rest of us take for granted. The UK's digital inequalities mirror its other inequalities. Those on the wrong side of the digital divide are those who are marginalised as a result of poverty, age, gender, disability, race, religion or class.

Yet social exclusion does not inevitably mean digital exclusion. Many poor families own smart phones, PlayStations and PCs. For them, the issue is how to harness the technologies they have to combat the inequalities that blight their lives – inequalities in income, education, housing and health.

Helping the digitally excluded to become not only digitally included but also digitally advantaged is a key theme of technology-enhanced learning research.

In the context of full-time education, three groups of learners are most at risk of exclusion: those who are disengaged, those who are hard to reach, and those with special educational needs.

IN THIS COUNTRY



OF PEOPLE RARELY, IF EVER,  
VENTURE ONLINE

In schools, colleges and universities, technology can transform curricula, practices and cultures. For example, accessible learning management systems and assistive technologies make it easier for students with special needs to engage with the curriculum and with other students. Teachers can use interactive media and related technologies

to open up the curriculum and engage disaffected learners. Hard-to-reach students who feel intimidated or rejected by educational institutions, can now learn at home, in the local café or community centre, or in their hostel. Once online with a mobile device such as a smart phone or an iPad, hard-to-reach students are in control of their learning.

People need to be able to use technology that does what they want in places where they feel valued and comfortable. Digital inclusion therefore requires:

- innovative technologies that address the unique needs and abilities of some students, particularly those with special education needs;
- teachers, parents, carers, support workers and community leaders to be creative and imaginative in terms of how and where they use technologies with learners;
- communities, institutions, local authorities and government to promote creative, transformative digital inclusion practices.

# In action: Inter-Life

Many young people enjoy exploring virtual worlds such as Second Life through the persona of an avatar. Liberated from the constraints of reality, they can change everything about themselves. A diffident boy can become an invincible warrior. A shy and insecure girl can turn herself into a princess.

The Inter-Life<sup>30</sup> research team set out to investigate whether the creative possibilities of virtual worlds had applications beyond play. Could they, for example, help young people cope with important transitions such as from school to university or from local authority care to independent living. With this in mind, they set up two virtual islands: the first for over-18s to tackle school-to-university and within-university transitions; and the second for 13 to 17-year-olds to work on creative activities and skills related to leaving a care home.

On the islands, the young people participated in research and reflective activities, gaining insights into emotions and developing their problem-solving skills. They planned and executed creative activities (with support) that expressed a need, issue, or concern, an interest or a personal liking. Island 2 became a space ‘in

tension’ between home and school, a space that often challenged its users to act more openly than was their custom.

Island 2 became an authentic place to work and socialise – for the research team as well as the young people. It developed both a sense of place and of group history as the teenagers customised it, creating working areas, buildings and presentation tools. They became emotionally engaged with their island and explored issues of identity through community activity and dialogue. Accounts of avatar customisation and personalisation also indicated that the experiences of island life were capable of boosting their self-esteem.

On both the islands, users were shown to ‘map’ – or relate – their experiences in the virtual community into their life in the real world. Lessons learned in the virtual world were lessons that did not need to be re-learned in the real world.

As one of the Inter-Life researchers said: ‘Our hope was not just to disseminate knowledge, but to see the kids construct knowledge. Some of them were interested in making films

depicting a problem with vulnerability at a point of transition in their lives. Think of bullying, teasing, taunting, betrayal. Suppose they met with their avatars on the island and used the film as a stimulus, saying “this is the problem, how can we fix it?” All we’ve done is provide them with the space and the opportunity to make a contribution.’

<sup>30</sup> [tel.ac.uk/inter-life/](http://tel.ac.uk/inter-life/)



Once online with a mobile device such as a smart phone or an iPad, hard-to-reach students are in control of their learning.



# 10 Know

Employ tools to help learners make sense of the information overload.

Picasso is reputed to have said: ‘What good are computers? They can only give you answers.’ Answers may provide information, but it’s knowledge that really matters. The knowledge to frame questions, make connections and to help us work out whether the answers are the ones we’re looking for. Search engines can be a quick route to information, but they sometimes close down rather than open up possibilities. We are still finding out how technology-enhanced learning can help students and adults become skilled finders of information and discerning consumers of it. More than ever before, people need to be able to evaluate the credibility and validity of what they find in the digital world.

Technology has contributed massively to the problem of too much information, but it can also help. For instance, Amazon’s recommender systems use information about our prior purchases to suggest books or DVDs that we might like based on what people with a similar profile have bought. This may help with wading through the oceans of online choice, but it can be a bit hit or miss. On TripAdvisor, knowledge about hotels and destinations builds cumulatively as a result of

IF...

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# KNOWLEDGE = INFORMATION + MEANING

## WHERE DOES THE MEANING COME FROM?

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social interaction, but we need to be careful and learn how to interpret it.

One reason that computers aren’t very good at differentiating information and knowledge is that knowledge is built socially. The culture that we live in determines what we need to know and what we value. This knowledge comes from lots of sources: our parents, our friends, our education and our experiences. We tell stories about all these things and construct knowledge for ourselves and others in the process.

Technology speeds things up. Useful knowledge changes quickly and has become more fluid, contingent on local circumstances and requirements. This has eroded the concept of a standardised body of knowledge

or an agreed canon of what should be taught. In fact, thinking deeply about what knowledge we need to teach in the 21st century is one of the great contributions that technology-enhanced learning research can make.

The storage and transmission capacities of computers enable us to share information more readily than in the past, but if knowledge = information + meaning, where does the meaning come from? Computers excel at retrieving something from memory. But they’re not so good at reflecting or drawing on experience, yet.

The worldwide web is growing ever larger. This growth has prompted much discussion of how it might evolve to provide access to useful, timely, trustworthy information, while



## It is naïve to assume that simply bringing data into the classroom will enable new, or better, or faster learning.

not overwhelming its users with vast amounts of data. Tim Berners-Lee, an inventor of the web, and others have proposed remaking what already exists as a ‘semantic web’ of resources. Clear description of the meaning of web content would allow better linkage of online content, search engines would apply the same kind of reasoning that people use, and web users would be offered a more seamless experience.

This grand vision of a ‘next-generation web’ has been slow to develop. But increasing numbers of government and public bodies, research organisations and museums have recognised the potential benefits of linking data from multiple sources. This has enormous educational potential, but it is naïve to assume that simply bringing data into the classroom will enable new, or better, or faster, learning.

Governments often refer to the knowledge economy. They aspire to an economy that is driven by innovation, change and growth to ensure global competitiveness. Increasingly, this is a digital economy – the result of digital networking and communication infrastructures that provide a global platform over which people and organisations can interact, communicate, collaborate and share information.

It relies on skilled labour; even manual jobs now need people who are comfortable with technology. Grappling with vast amounts of information and being able to transform it into knowledge requires an education that encourages creativity, clear thinking, independence and ingenuity. Technology can help, but it alone is not the solution. Teachers are still vital in the translation of information into knowledge. And students must be actively involved too – technology can support the process, but it cannot do it for them.

Technology-enhanced learning research is helping us to rethink the nature of knowing by changing the ways in which information

is presented and understood, challenging our prior knowledge and helping us to seek out new directions and associations.

In 1910 the educational philosopher, John Dewey, wrote: ‘The distinction between information and wisdom is old, and yet requires constantly to be redrawn. Information is knowledge which is merely acquired and stored up; wisdom is knowledge operating in the direction of powers to the better living of life. Information, merely as information, implies no special training of intellectual capacity; wisdom is the finest fruit of that training.’<sup>31</sup>

<sup>31</sup> Dewey, . 1910 ‘School Conditions and the Training of Thought, Chapter 4 in How we think. Lexington, Mass: D.C. Heath, (1910): 45-55



# In action: Ensemble

The Ensemble TEL programme project<sup>32</sup> explored how web-based resources might be incorporated into teaching and learning in higher education. It examined how teachers and learners use the web, and how data and other linked online resources are mobilised to meet learning aims and suggest new directions for enquiry. Various ‘mediating’ practices help students make good use of the vast amount of data. These range from teachers making selections and recommendations to students (for example, by helping them to narrow down the results of semantic web searches) to rich web interfaces and visualisations which present large, complex data sets in more accessible, explorable formats.



Thinking deeply about what knowledge we need to teach in the 21st century is one of the great contributions that technology-enhanced learning research can make.

For instance, the Ensemble team worked with teachers and undergraduate plant scientists to develop an interactive timeline of plant evolution which brought together datasets, texts, images, maps and publications, allowing students an overview of trends and patterns before exploring particular aspects in depth.

The team also worked with environmental education teachers to develop an assessed ‘case study’ in which undergraduates decided the best location for a hydroelectric power station. To do so, they had to draw on authentic data such as climatic records and measurements of river speeds and heights over time. They were helped by a

combination of linked data and visualisation tools that enabled them to see patterns and resemblances in what might otherwise seem intractable, dense or vast amounts of information. These, plus crucially the teacher’s expertise in shaping and ‘bounding’ the case study – not too broad, not too directed – made for an engaging yet challenging activity.

<sup>32</sup> <http://www.ensemble.ac.uk/wp/>



The Ensemble plant evolution timeline draws live data from online sources to create dynamic visualisations.

# 11 Compute

Understand how computers think, to help learners shape the world around them.

We are living in a world of increasing interdependence and complexity. Science and maths underpin so much of everyday life: yet too few people really understand how the science and maths that affects their lives is done. That knowledge is essential if we are to be productive and engaged citizens of the 21st century. How else can we hope to understand stock market crashes, compare goods and services online, or assess competing arguments about climate change? Computational thinking empowers us to explore how systems and processes work, including societies, the spread of diseases, interacting technologies, and our own minds and bodies.

We need to distinguish computational thinking from creative computer programming (or ‘coding’). Both are relevant and important skills.

Computational thinking involves forms of dynamic problem solving that computer scientists practise, such as splitting problems into smaller parts, tracing how things work, finding ‘bugs’ in processes, recognising and analysing patterns. Given the centrality of computers in science and increasingly, social

science, computational thinking is an essential tool for making sense of the world.

Through computational thinking we gain a way of questioning evidence and assumptions, by building models and analysing patterns in data. Research suggests that even young children can make sense of some of these ideas, including estimation, interpreting evidence, and dynamic modelling. Although they originate in computer science and mathematics, they are important for the way we all think and act.



**This failure to understand anything of the invisible computer models that dominate our lives is dangerous.**

Yet, as Ben Goldacre says, in his book *Bad Science*<sup>33</sup>: ‘The process of obtaining and interpreting evidence isn’t taught in schools, nor are the basics of evidence-based medicine and epidemiology, yet these are obviously the scientific issues that are most on people’s minds.’

*Shut down or restart?*<sup>34</sup>, the Royal Society’s 2012 report into computing in UK schools, highlights another benefit of computational thinking. ‘We want our children to understand and play an active role in the digital world that surrounds them, not to be passive consumers of opaque and mysterious technology. A sound understanding of computer science concepts enables them to get the best from the systems they use, and to solve problems when things go wrong. Citizens able to think in computational terms are able to understand and rationally debate issues involving computation, such as software patents, identity theft, genetic engineering, and electronic voting systems for elections.’

A recent study of how people interpret computer outputs in their workplaces found that many people were completely unaware of the systems that underpinned their working lives. For example, people working in a pension

<sup>33</sup> Goldacre, B. (2009) *Bad Science* (London: Harper Perennial)

<sup>34</sup> Royal Society (2012) *Shut down or restart?: The way forward for computing in schools*. <http://royalsociety.org/education/policy/computing-in-schools/report/>



**Writing programs means children can make things happen, rather than have them happen without understanding how or why.**

company did not know that the spreadsheets they used every day were governed by formulae, rather than an arbitrary set of entries by managers. This failure to understand anything of the invisible computer models that dominate our lives is dangerous. If people are ignorant of what computers can and can't predict, they become potential victims, at the mercy of the programmers. Yet, in the words of the chief executive of a packaging company, when workers are introduced to the ideas behind the models, they develop a sense of 'empowerment' and 'job satisfaction'. These are new literacies that people need to be workers and citizens of the 21st century.

The skills of computational thinking can be taught with or without computers, by exploring how processes work, looking for problems in everyday systems, examining patterns in data, and questioning evidence. For example, banking crises can be explored as computational systems. Banks receive cash in deposits. They lend out most of this cash as loans. The system works smoothly until the point when there's a lack of confidence in the bank, the lenders demand their deposits back, and the bank doesn't have sufficient funds to

meet the requests. The bugs in the banking system can be repaired, for example by deposit insurance, but this can cause further problems, and so on. Visual techniques such as flow charts can show how these processes work, even if there's no computer present.

But computers make it possible to show the computational processes in action. They can show how things work, the bits behind the scenes that are often hidden – but which sometimes, especially when something unusual happens, people need to know.

Computers can also empower children to create and run programs, especially when using languages constructed with young people in mind. Writing programs means children can make things happen, rather than have them happen without understanding how or why. Children also become part of a vibrant global community of people who like to code and work together to change the way that we interact with our technology.

For example, Year 10 children from Blatchington Mill school produced a winning entry for the Pearson Innov8 national competition by

developing science ‘apps’ for mobile phones<sup>35</sup>. Their playful hands-on science experiments used the built-in functions of phones such as tilt sensors and voice recognition.

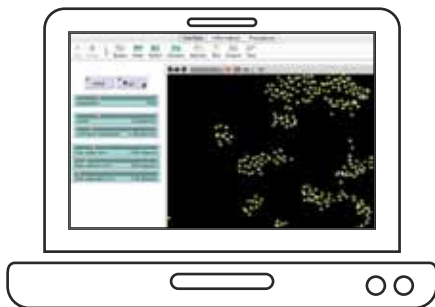
The Blatchington children were not just writing programs, they were engaged in software design. They set out specifications for interactive software, based on the requirements of the competition. They proposed software apps that exploited the features of modern mobile phones. They designed interfaces and produced storyboards for the interactive software. And they presented their solutions in text and video.

By programming computers themselves, people can come to see that software isn’t magic produced only by big corporations, but is based on some principles and processes that they can understand. Programming is not just grappling with long lines of code. Since the 1960s, there have been many attempts to design programming languages and systems that are accessible to the non-programmer – to everyone in fact.

<sup>35</sup> <http://innov8.pearson.com/>



# In action: Program or be programmed



A NetLogo program reveals how 300 birds, randomly scattered across the screen, start to clump together and form flocks with one bird in front. Each bird only knows about its nearest neighbours, yet the flocking behaviour emerges from three simple rules, shared by each bird. There is no leader bird!

There are many ways to get involved in programming. For example, not much more than £20 will buy you a single-board computer developed in the UK by the Raspberry Pi Foundation<sup>36</sup>. The foundation's goal is to stimulate the teaching of basic computer science in schools at minimal cost – with the ultimate aim of ensuring that people control computers rather than the other way round.

The foundation has found a ready market. Since the government announced that it was backing the teaching of programming, demand for the cheap, credit-card-sized computer has soared. It comes equipped with a processor similar to the one used in many smart phones, a memory chip, an Ethernet port to connect to the internet and a couple of USB ports.

After plugging in a keyboard, mouse and screen, children should be able to use the Pi's open-source software to write their own code.

## **Programming for everyone**

Scratch<sup>37</sup> is a programming language that, to quote its popular website, 'makes it easy

to create your own interactive stories, animations, games, music, and art – and share your creations on the web'

The key design idea is that as people create projects and programs for themselves, and then share the fruits of their programming, they come into contact with key mathematical and computational ideas. Thus while learning to think creatively, they also come to think computationally. This is programming in every sense but one: it is not just for programmers.

Scratch is the latest in a long line of programming languages for children. The first of these was Logo, developed at MIT nearly 50 years ago and updated several times over the decades<sup>38</sup>. A recent addition to the list is NetLogo<sup>39</sup>, a modelling system that, based on writing simple programs in a dialect of Logo, allows people to build, tinker with and share dynamic models of anything from dynamic art to models of evolution.

This ability to model how complex systems develop over time comes courtesy of modellers that give instructions to hundreds or thousands of independent

‘agents’ all operating concurrently. This way of thinking – that pattern and structure emerge from simple rules applied to many interacting agents – underpins whole areas of modern science and social science. It is a key component of computational thinking that provides ways to think about evolution, randomness, 3D graphics and an ever-expanding list of ideas.

Logo, NetLogo and Scratch aim to tap into activities that children (and adults) find naturally interesting (drawing, emergence and games, respectively). One of the key differences between Scratch and its predecessors is that programs do not consist of lines of text-based code. There have been several attempts to achieve non-textual programming systems, for example, ToonTalk<sup>40</sup>. The latest addition to the range is MIT’s App Inventor<sup>41</sup>. App Inventor is a programming system, not dissimilar to Scratch, that lets novice programmers easily create games on mobile phones. Instead of writing code, you visually design the way the app looks, and using simple scratch-like ‘blocks’, specify how the app works.



Is the Raspberry Pi a simple, cheap solution to children’s lack of programming skills?



Scratch lets you write programs by slotting jigsaw pieces of code together.

<sup>36</sup> <http://www.raspberrypi.org>

<sup>37</sup> <http://scratch.mit.edu/>

<sup>38</sup> A powerful recent version may be found at  
<http://www.r-e-m.co.uk/logo/?comp=imagine>

<sup>39</sup> <http://ccl.northwestern.edu/netlogo/>

<sup>40</sup> [www.toontalk.com](http://www.toontalk.com)

<sup>41</sup> <http://www.appinventor.mit.edu/>

# 12 Construct

Unleash learners' creativity through building and tinkering.



Watching young children make sense of the world teaches us an important lesson: that people learn best when they are making things, and sharing what they've made with each other. Making something produces something to talk about, reflect upon, and ultimately learn with. And it presupposes that one has something with which to build – blocks, or paints, or musical instruments.

In the past, most things were more or less unbuildable – playing around with the forces of gravity, or modelling the spread of diseases with pencil and paper has always been out of reach for the vast majority. But now, with computers, literally *anything* is possible.

Computers open doors which used to be closed to everyone except the very few – the mathematicians and scientists and musicians who could build things in their heads. Now anything is potentially buildable on a computer, and if it's buildable, it becomes thinkable, discussable, and ultimately, learnable. As Seymour Papert said, in describing his theory of 'constructionism' some 20 years ago<sup>42</sup>, the special thing about building is that it constructs a 'public entity,

whether it's a sand castle on the beach or a theory of the universe'.

In similar vein, Douglas Thomas and John Seely Brown in 2009<sup>43</sup> put forward a new model of education that fuses learning as reflecting, learning as making, and learning as becoming. Creative play and improvisation are essential for prospering in a complex and changing world.

The programming systems in Chapter 11 give some potent examples of what can happen if people – even very young people – are given powerful tools that allow them to construct and share ideas embodied in *things* (including virtual things).

Reflecting on what you have constructed is a key part of learning. Until now, this lesson didn't easily translate into learning more generally. But now, with computers, ideas that could only live in the minds of people can have a life on the screen – bringing them alive, and, most importantly, giving people the chance to construct *mental* representations of dynamic systems alongside virtual ones.



**Anything is potentially buildable on a computer, and if it's buildable, it becomes thinkable, discussable, and ultimately, learnable.**

<sup>42</sup> Papert, S (1980) *Mindstorms: Children, Computers, and Powerful Ideas*. (Basic Books: New York)

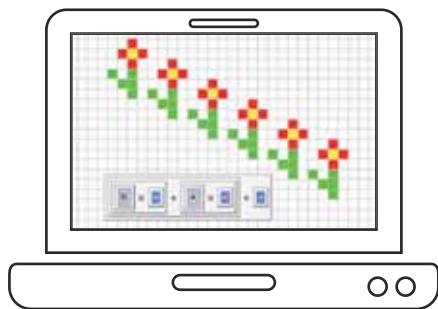
<sup>43</sup> Thomas, D. & Seely Brown, J. (2009) *A New Culture of Learning: Cultivating the Imagination for a World of Constant Change* <http://www.newcultureoflearning.com/newcultureoflearning.html>

# In action: MiGen

Mathematics is the science of patterns. Identifying, analysing, and predicting patterns is the source of the power of mathematics – whether it's a sequence of numbers, the structure of shapes, the change in the climate, the spread of a virus. But finding patterns in a few cases is not enough for mathematicians: the trick is to express the pattern so that it's true for all cases – to generalise it.

This turns out to be difficult for learners. The problem is that if you ask someone to spot a pattern, say 'how many tiles do you need to make a "train track pattern"?' a natural strategy is to count. Why not? We can encourage people to think a little more by asking them to predict the number of tiles when it's very large, but even then, asking 'how many?' cues people into counting in some way.

The trick is to look at the *structure* of the pattern, to see it as something that is repeated to form a rule. The classic way to do this is to use algebra – call the number of 'building blocks'  $N$  and go from there. But that is *precisely* what we are trying to teach! We're asking learners to use the language of algebra, before they understand what that language is supposed to be about.



**Building the flower model is a two-part process. First, students **construct**; second they **express**. Keeping hold of the relation between the constructed picture and the 'equation' help students bring meaning to the symbols.**

MiGen<sup>44</sup> is an intelligent, computer-based support system intended to help pupils get to grips with algebra without the difficulty of manipulating abstract symbols. Young people enter a 'microworld' that encourages them to *construct* patterns in a colourful, dynamic and visual format. They are nudged to explore the nature of relationships and uncover rules

for themselves. And they are empowered to present their answers creatively, using simple sequences of coloured tiles.

In the MiGen microworld, students bump into powerful ideas. They learn to move from the specific to the general. The important lesson here is that students first construct patterns, and only then, when they have built a computer 'model' of the tiling pattern, do they have to express what they have constructed in some form. That form is a sort of algebra, but it looks a bit different. It is learnable because it gives students a language to talk to each other about what they have made. In other words, the system helps students to *see the general in the particular*; to keep hold of the link between what they've constructed, and the rule that expresses that construction. After three or four lessons using MiGen, studies in five schools showed that students were able to apply their knowledge to conventional generalisation tasks.

MiGen adds a new dimension to the idea of construction, through its artificial intelligence techniques that support teachers. Intelligent systems that focus only on the students can

end up marginalising teachers. But MiGen keeps them in the picture by providing a suite of tools to monitor students' progress and to view and compare their constructions. Two students may, for example, see a pattern in two different ways, both of which are correct. They may both arrive at an algebraic expression for their pattern. But unless they know what the other has done they will not realise that rules that look completely different can in some sense be the same. MiGen can spot the potential benefit of their collaboration and help teachers group them together.

As well as highlighting fruitful collaborations, the system can help teachers gauge students' progress, and pinpoint those in need of assistance. So the idea of constructionism is extended to harness the techniques of AI, to help students construct what matters, to notice what goes wrong, and – most critically – to reflect on and share as productively as possible, what they have built.

44 <http://migenproject.wordpress.com/>



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